3D printing technology for RF and THz antennas

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***Abstract* - Additive manufacturing (AM), or often called 3D printing is an emerging research area which has received much attention recently. It allows 3D objects with arbitrary geometry to be printed automatically layer by layer. 3D printing technology offers several advantages compared to conventional manufacturing techniques such as capability of more flexible design, prototyping time and cost reduction, less human interaction and faster product development cycle. This paper reviews state-of-the-art 3D printed antennas from microwave to THz frequencies and offers practical and futuristic perspectives on the potentials and challenges of 3D printed antennas.**

***Index Terms* — Additive manufacturing, 3D printing, antenna.**

1. Introduction

Additive manufacturing (AM), often called “3D printing”, is an automated fabrication technology to make 3D objects directly from digital data. Recently, AM has received much attention with impressive demonstrations ranging from musical instruments, to vehicles, to housing components or even entire buildings. Many different structural materials such as metal, polymer, ceramics, concrete and even bio-compatible materials have been incorporated in various 3D printing technologies. Due to its ability to realize desired structures with arbitrarily designed material spatial distribution, 3D printing technology has been argued to be the future of manufacturing as it offers huge potentials to revolutionize both the design and manufacturing procedures. Since any EM structure can be viewed as a spatial distribution of EM properties, AM processes has the potential to spatially structure the EM property to create arbitrary EM materials. Compared to conventional manufacturing methods, AM approach has several advantages including: arbitrary complexity, digital manufacturing and waste reduction.

Various 3D printed antennas have been reported taking advantages of the AM technology. Antennas of different structures such as horn antennas [1], patch antennas [2], meander line antennas [3], gradient index (GRIN) lens antennas [4] and reflect-array antennas [5], made of different material such as all dielectric antenna [6], all metal antenna [7] and dielectric metal combined antenna [2, 4, 5], working at different frequencies from GHz to THz have been realized using different 3D printing techniques [8].

2. Overview of 3D Printing Techniques

At the present time, there are many kinds of 3D printing techniques, all of which follow the basic steps of AM, for example, generating individual physical layers and combining them together. Diverse materials such as metal, plastic, ceramics or even bio-compatible materials can be used in the generation of the physical layers. According to the methods of generating physical layers and bonding adjacent layers together to form an object, five basic categories of AM processes are commercially available [9], including selective sintering and melting, powder binder bonding, polymerization, extrusion and layer laminate manufacturing (LLM). Key aspects of these five processes are summarized in Table 1.

Table 1. Summary of key characteristics of the five basic categories of AM processes.

Classification	Available material	Process Temperature	Resolution	Strength	Can print overhanging structure?	Print multiple materials
Sintering and melting	Polymer, metal and ceramic	High temperature	Low	Strong	Yes	No
Powder binder bonding	Polymer, metal and ceramic	Depending on material	Moderate	Moderate	Yes	No
Polymerization	Polymer	Room temperature	High	Moderate	Need support material	Yes
Extrusion	Polymer	200 - 300 °C	Low	Strong	Need support structure	Yes
Layer by Layer bonding	Paper, plastic and metal	Depending on material	Low	Moderate	Yes	No

3. 3D PRINTED ANTENNAS

AM technology enables flexible and rapid realization of structures with arbitrary shapes and complexity. It has been successfully applied in many scientific and industrial areas such as biomedical, aerospace industry, toy industry, architecture and landscaping [9]. In the following sections, applications of AM techniques for realizing 3D printed antennas are reviewed. A number of antenna examples printed by different AM techniques including electron beam melting, powder binder bonding, stereolithography, polymer jetting, conductive ink printing and fused deposition modeling are presented.

(1) Antenna printed using sintering and melting

Sintering and melting is an AM technique which uses laser or electron beam to selectively melt powder material and build 3D structures. In [7], two horn antennas operating at Ku-band are printed by employing the electron beam melting (EBM) technique. It is observed that the surface roughness of 3D printing methods can influence the antenna performance such as gain. This issue will be more severe for higher frequency bands such as mmW and THz. Moreover, the relatively coarse printing resolution can be achieved by EBM and SLS may also limit their applications for those higher frequency bands.

(2) Antenna printed using powder binder bonding

Another 3D printing technique that is capable of printing pure metallic structures, the powder binder bonding technique, is utilized to realize a 3D volcano smoke antenna

[10] for ultra-wide-band (UWB) applications. The antenna is built using steel material. However, due to the low conductivity of steel, two methods to improve the antenna performance are applied. One method is covering the 3D printed prototype with copper tape. The other method is electroplating the prototype with copper.

(3) Antenna printed using stereolithography (SL)

Stereolithography is one of the most accurate AM techniques. It has also been applied in the realization of microwave antennas. An example using stereolithography and electroplating approach to build horn antennas at Ku-band is reported in [1]. Two horn antenna prototypes are first printed using polymer. Then, the stereolithography printed parts are coated by conductive silver ink as a seed layer and electroplated with copper. Because of the high resolution of the stereolithography technique, it can be applied in the realization of finer structure than most of the other AM techniques and therefore achieve higher operating frequency.

(4) Antenna printed using polymer jetting

Polymer jetting is another kind of AM technique based on polymerization. Ref [5] reports an example of polymer jetting printed dielectric reflect array as high gain antennas operating at W-band (75-110 GHz). After the polymer structure is printed, electroplating process is applied to metalize the backside of the reflect array. In [6], all-dielectric antenna operating in the mmW / THz frequency range has also been realized by the polymer jetting 3D printing technique [11]. This printed all-dielectric horn antenna demonstrates comparable or better radiation performance compared to a copper horn antenna with the same geometry. Another example using polymer jetting technology to print all-dielectric microwave lens antenna is reported in [4] in which a broadband 3D Luneburg lens antenna operating from X to Ku-band are printed by employing the polymer jetting technique. The above mentioned antenna examples show that the polymer jetting technique is a very good candidate in realizing 3D printed antennas, even up to THz frequency.

(5) Antenna printed using fused deposition modeling

Fused deposition modeling (FDM) technique has the ability to print a large number of thermoplastic materials. In [3], a 3D meander line dipole antenna is printed on a V-shaped substrate using the FDM technique. The conductive part of the antenna is realized using printed conductive ink. The curing process of the printed conductive ink is at 85 ºC for 15 minutes to reduce the resistivity. In [2], a microwave patch antenna is realized by FDM and an ultrasonic wire mesh embedding process. The substrate of the patch antenna is created using a FDM 3D printer and the conductive part of the antenna is realized using an ultrasonic machine which has the ability to embed copper wires on a 3D surface. Compared to the conductive ink approach, the ultrasonic wire embedding technique is performed at room temperature and therefore will not influence the thermoplastic substrate. In addition, since pure metal wire is used, the conductivity of the material is much larger than that of the conductive ink.

4. Challenges and Potential Solutions

It has been argued that 3D printing could be the future of manufacturing due to its ability to print structures with more flexible design than conventional methods. Recently, rapid progress has been made in the 3D printing area. However, a number of challenges such as surface roughness, resolution, limited electromagnetic (EM) property range, performance of printed conductor and multiple-scale and multiple-material still need to be resolved before advanced functional antennas can be printed in a 3D fashion robustly. Also, novel antenna designs utilizing arbitrary 3D spatial distribution of EM (ε, μ and σ) needs to be investigated which may have the potential to revolutionize antenna design methodology and lead to unprecedented performance.

5. Summary

In this paper, recent progresses and challenges for 3D printed antennas are reviewed and discussed. The reported examples include a number of antennas printed by various AM techniques. There are still substantial challenges need to be overcome before complete and fully functional antennas and microwave systems can be truly realized via AM. However, further investigation and development of 3D printing technology in the areas of mechanical engineering, material science and engineering and electrical engineering will no doubt lead to a new paradigm of 3D printed antennas, other microwave components and systems.

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